Spectrum synthesis of sharp-lined A and B stars

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Abstract.

I have carried out spectrum synthesis of $R = 120,000$ spectra of several A and B stars having $v \sin i$ less than about 6 km s^{-1}. The following conclusions emerge: (1) As T_e descends from 12,000 to 8,000 K, microturbulent velocity ξ deduced from abundance analysis rises steadily from 0 to about 5 km s^{-1}. (2) Stars with $\xi \geq 1$ km s^{-1} show direct evidence in their line profiles of the presence of macroscopic gas motions in the form of line asymmetry (bisector curvature) which grows with increasing ξ. (3) Above $T_e \approx 9000$ K, both weak and strong spectral lines can be modelled with reasonable accuracy by conventional LTE spectrum synthesis with a single assumed model atmosphere, abundance table, $v \sin i$, and an appropriate (constant) value of ξ. (4) In contrast, at $T_e \approx 8,000$ K the weak spectral lines are much narrower than the strong lines. If the synthesis model is constrained in $v \sin i$ and ξ by the weak lines, *no* satisfactory model can be found for the strong spectral lines. Consequently, chemical abundances for such stars based only on strong lines may be significantly in error.

In cool stars, we learn a lot about conditions in the stellar atmosphere from studies of the *shape* of line profiles, which often contain much information about the velocity fields present. No such studies exist for non-magnetic A and B stars because most of them rotate so rapidly that the profiles contain very little information except about the global rotation.

With current spectrographs and detectors, it is practical to search for and observe A and B stars of $v \sin i \leq 6$ km s^{-1}, in which information about local photospheric velocity fields is detectable in the line profiles. I have observed about a dozen such stars with R = 120,000 with the Aurélie spectrograph at OHP or with the f/4 spectrograph at CFHT. The observed spectra are modelled by spectrum synthesis.

This project has two main goals. The first is to test the adequacy of the LTE models usually used to study A and B stars by seeing if a single model (specified by T_e, $\log g$, rotational velocity $v \sin i$, microturbulent velocity ξ, and abundance table) can correctly reproduce the observed line profiles (which because of the small values of $v \sin i$ contain much information about the local stellar line profile) of both very weak and strong metal lines. The second is to search for direct evidence in line profiles of convective or other velocity fields, and to study the relationship of any such evidence to the classical microturbulent velocity ξ derived from abundance analysis.

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The observed spectra are modelled using a version of my spectrum synthesis programme ZEEMAN. This programme calculates line profiles in LTE, using a suitable Kurucz model atmosphere for each star. The programme attempts to optimize the fit of the calculated profile to the observed one, line by line, by adjusting $v \sin i$, radial velocity v_r, ξ, and the abundance of the element producing the line. All gf values used have been carefully tested.

This paper presents results for two stars, HD 193452 (Sp = HgMn, T_e = 10,500 K, $\log g = 4.0$), and HD 108642 (Sp = Am, T_e = 8,100 K, $\log g = 4.1$). For HD 193452, it is found both from Blackwell diagrams and from the line profiles that $\xi \leq 1$ km s^{-1} and $v \sin i \leq 2$ km s^{-1}. Comparison of the values of ∇_{rad} and ∇_{ad} shows that only very mild convective instability is expected, in agreement with the small ξ found. The calculated line profiles fit the observed lines extremely well, as may be seen in Figure 1 below showing representative fits to two iron lines.

For HD 108642, the *weak* lines show that both $v \sin i$ and ξ are ≤ 3 km s^{-1}. However, Blackwell diagrams suggest a value of ξ near 4 km s^{-1}, and a comparison of the values of ∇_{rad} and ∇_{ad} shows that the atmosphere should be very unstable. **Remarkably, the profiles of the strong lines are much wider than the corresponding profiles of weak lines, and strongly asymmetric**, with deeper blue wings than red; modelling of single strong lines gives $v \sin i$ of about $6 - 8$ km s^{-1}. Furthermore, calculation of line profiles for the strong lines shows major discrepancies between the theoretical profiles computed with constant ξ, and the observed profiles (see Figure 1). It is clear that the strong line profiles contain much information about photospheric velocity fields which is not included in the simple model used. It is also clear that abundances based on these strong lines are likely not to be very accurate.

A number of other stars have also been modelled, with the following results. For stars with $T_e > 10,000$ K, ξ is found to be below about 1 km s^{-1}, and line profiles are very well described by LTE synthesis even when $v \sin i \approx 1$ km s^{-1}. Below 10,000 K, however, the deduced values of ξ rise above 2 km s^{-1}, and the line profiles are increasingly asymmetric, presumably due to increasing velocities in the atmosphere. At 8000 K, the deduced $\xi \approx 4$ km s^{-1}; the intrinsic line profiles of strong lines are much wider, and more asymmetric, than those of weak lines, and very poorly described by the spectrum synthesis. It seems clear that classical analysis of these stars is a very rough first approximation only. However, this profile structure is capable of furnishing much further information about the nature of velocity fields present in these A stars.

This work extends the studies of Gray (1992, chapter 18) and others on line profile shapes of stars near the main sequence. Gray has shown that main sequence stars show line asymmetry that changes with T_e; cool stars have lines that are deeper on the red wing, while late A stars have lines that show a deeper blue wing. My work includes stars between about A5 and B9, and I find that the asymmetry in spectral lines, when present, is always in the sense of a deeper blue line wing, but that this asymmetry dies out at about 10,000 K. This

asymmetry suggests that convection in the photospheres of A stars is composed mainly of small rising columns of hot gas balanced by larger, slower downflows. This is opposite to the behaviour observed in the sun, and to that predicted by numerical experiments for A stars (e.g. Freytag et al 1996). It is not clear what physical difference between convection in A and G stars could lead to such a fundamental difference in convective structure.

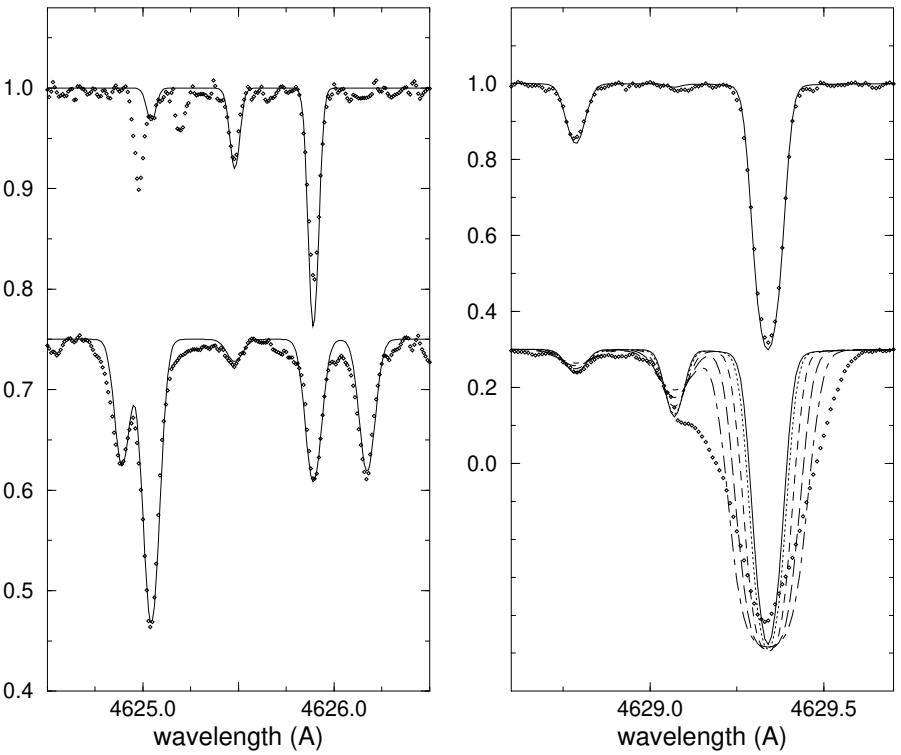

Figure 1. Observed (triangles) and model (curves) line profiles for two spectral regions of HD 193452 (upper profiles) and HD 108642 (lower profiles). For the Fe II line at 4629 Å in HD 108642, the model lines have ξ increasing from 0 to 4 km s^{-1}.

References

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